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FIG. 2

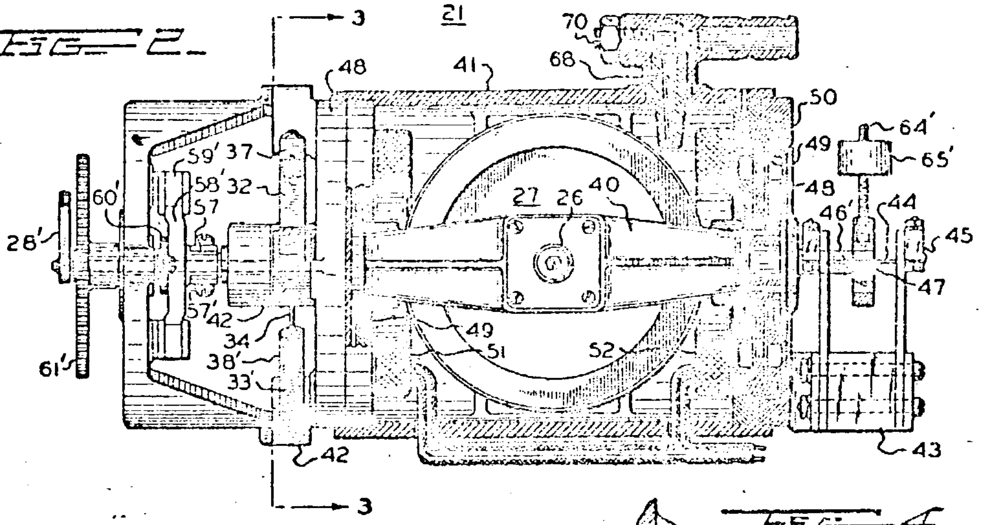


FIG. 3

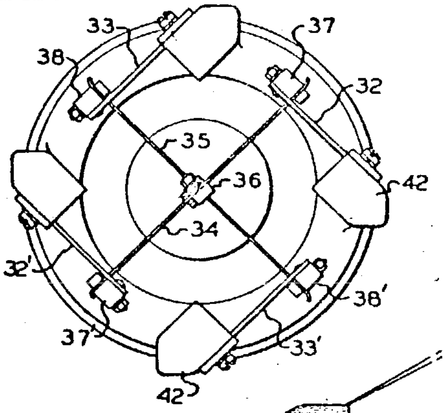
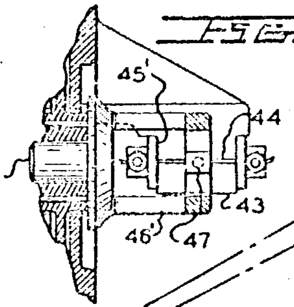


FIG. 4



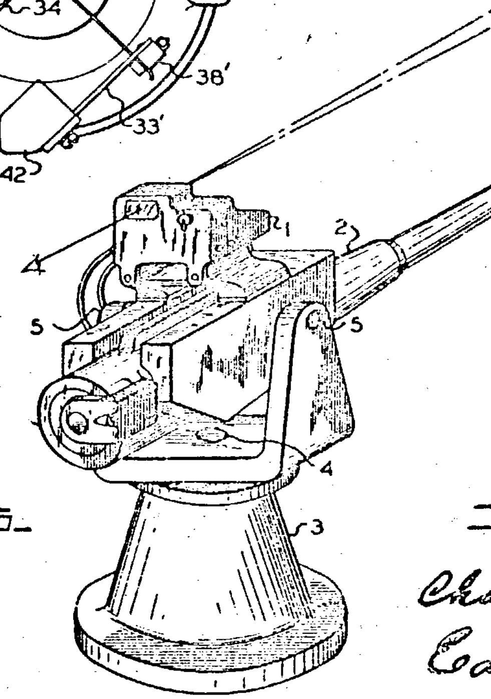


FIG. 6

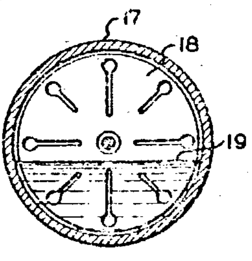


FIG. 5

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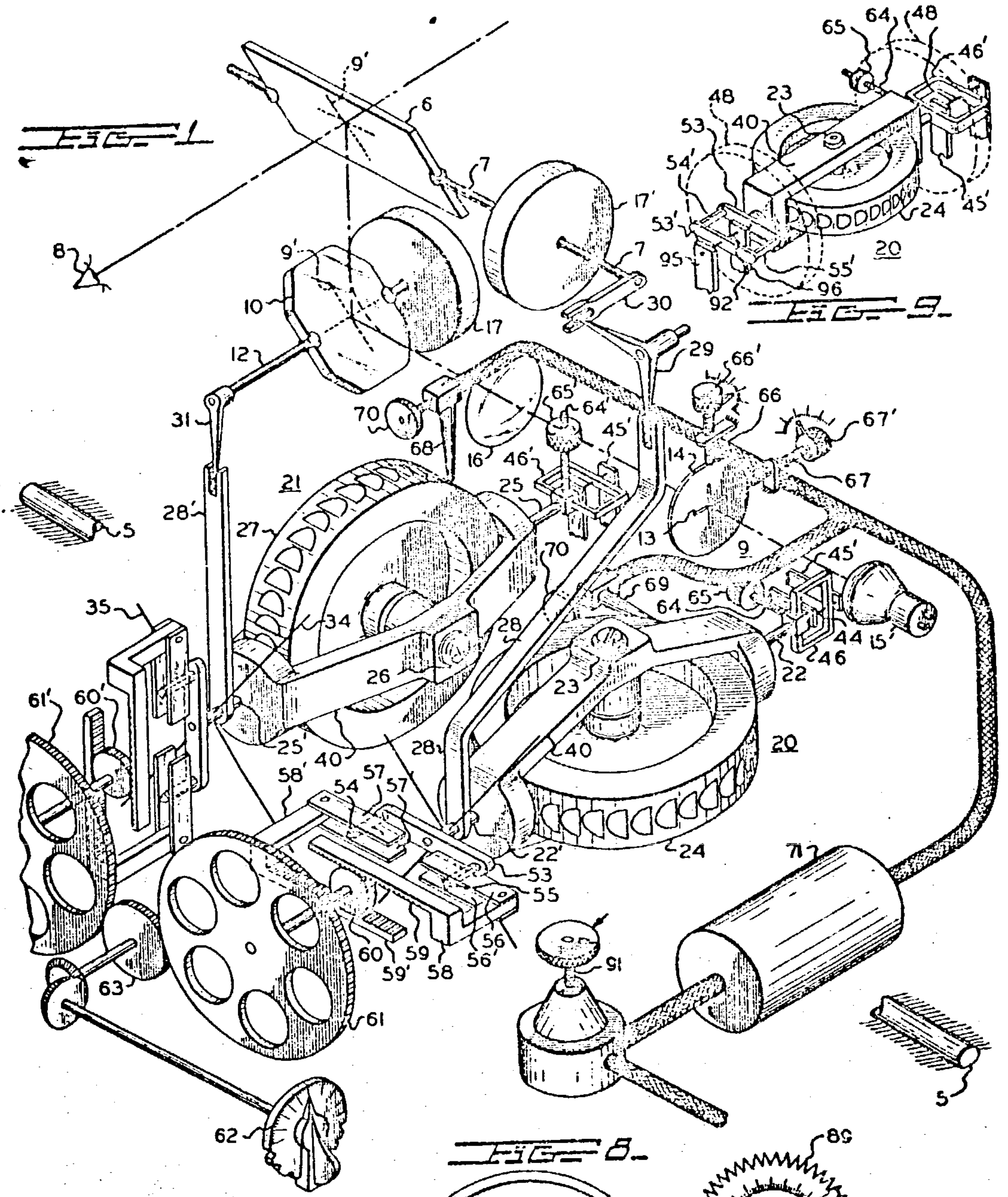
FIG. 1

FIG. 9

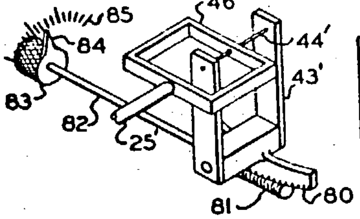
FIG. 7

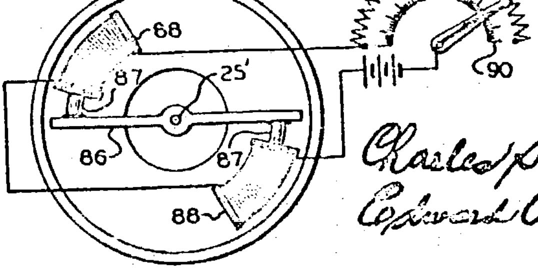
FIG. 8

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PATENT No. 505,357 ISSUED AUG. 24, 1954

Lead Computing Devices

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Application January 25, 1943, Serial No. 499,278
42 Claims

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This invention relates to lead computing or rate measuring devices, particularly, though not exclusively, useful in fire control apparatus for the aiming of guns such as antiaircraft guns, where the speed of the target is relatively great.

In apparatus to control fire at a moving target, it is necessary to advance the line of fire with respect to the line of sight by an angle depending on the speed of the target and on the time of flight of the shell. Many forms of rate devices have been suggested for this purpose. One form, which may be termed the "director" type, utilizes a manually driven sighting device which controls the motion of the gun mount through some kind of servo-mechanism. This has the disadvantage of controlling the power for operating a massive element from the operation of relatively light parts, with the result that the equipment involves excessive complication.

In another suggested form, which may be called the "disturbed sight" type, the primary source of power is applied to the gun element, the motion of which is applied to the sighting element through a rate device, for introduction of the "lead" angle. In theory, this avoids some of the difficulty of the director system, but so far as we are aware, apparatus of this kind has not proved successful. The force or torque applied to the sighting element is determined by the motion of the gun, but the operation of the system is controlled by the gunner in accordance with the motion of the line of sight. Whenever the line of sight does not move at a constant angular velocity, a false prediction is given by reason of the difference between the angular velocity of the line of fire and that of the line of sight; furthermore, the system may be unstable in that transients, when once introduced, will not decay but will increase indefinitely with increasing time.

It has now been discovered that certain conditions of stability and minimization of transient and dynamic effects must be attained for satisfactory operation, and that these conditions can be met only when a proper relation between the physical quantities involved in the construction of the apparatus is satisfied.

In the present invention, it is therefore proposed to control the line of sight in accordance with the rate of movement of the gun by means of a spring-centralized gyro element constructed in accordance with a correct relation between the several physical quantities, as will be hereinafter described in detail. It may here be briefly mentioned that the quantities affecting the precessional displacement of the gyro are the moment of inertia about the precession axis, the coefficient of damping for angular displacement about said axis, and the elastic coefficient of the springs opposing said angular displacement.

One of the requirements is that the moment of inertia shall be small and that the damping coefficient and the elastic constant shall be relatively large. Likewise important is a relation between the damping and elastic coefficients whereby the prediction error caused by angular acceleration is neutralized, and stability is maintained. It is also an essential feature of our invention that, when stable conditions have been once established, they are maintained under all possible circumstances of operation.

A new and improved type of rate gyroscope is also employed, since the conventional type does not give a sufficiently accurate indication for the purposes of this invention. The indications given by conventional gyroscope indicators which use ball bearings for suspending the gimbal frame are particularly subject to errors for small angles of precession.

Another feature of the invention is the use of means for applying what may be termed a bias torque to the gyro to compensate or correct for the effects of gravity, wind, etc. acting on the shell. This means may be embodied in several forms, one of which is particularly useful in automatically applying a proper superelevation for correction of gravity in any position of the gun.

Referring to the drawings illustrating the preferred form of the invention, Fig. 1 is a diagrammatic perspective view of the gyroscopic and optical elements as mounted on the gun or dummy gun; Fig. 2 is a vertical section of the azimuth gyro of this unit; Fig. 3 is a rear elevation of either gyro, showing the spring suspension employed thereat; Fig. 4 is a horizontal section through the forward spring suspension of the gyroscope; Fig. 5 is a section through one of the oil dampers employed on the optical mirrors; Fig. 6 is a perspective view showing the complete sight as mounted on the gun; Fig. 7 is a detail, in perspective, showing a modified method of introducing acceleration corrections, such as those due to wind or gravity; Fig. 8 shows a still further modification in such corrections; and Fig. 9 is a perspective view of a modified form of rate gyro.

As shown in Fig. 6, the entire sight and computing unit may be housed in a box 1 which may be directly mounted on the gun 2 or a dummy gun. The gun is shown as mounted in the usual manner on a base 3 for rotation in azimuth about a normally vertical axis 4 by any suitable mechanism (not shown), and for similar adjustment in elevation about normally horizontal trunnions 5, 5. For the sake of simplicity, such details as the shock mounting of the box 1 on the gun to prevent damage from gunfire are omitted.

The optical system is represented as comprising a plain plate glass or unsilvered mirror 6 which is normally mounted in a 45° position on normally horizontal trunnion axis 7 parallel to axis 5—5. The gunner, with his eye at 8, looks through this mirror directly at the target, and also sees an image 9′ of the reticle 9 reflected onto the surface of the mirror 6 from a second mirror 10, as illustrated by the dash-and-dot line. The mirror 10 is also normally positioned at an angle of 45° about the trunnion axis 12, which remains parallel to the gun bore. The reticle is shown as in the form of crossed narrow slots 13 in an opaque disc 14 placed in the path of the beam from a lamp 15 and a collimating lens 16 which directs the image 9′ of the reticle on mirror 10. Each mirror is preferably heavily damped about its axis of rotation, as by means of fixed oil containing housings 17, 17′ and slotted discs 18 within each (see Fig. 5), which are partially immersed in the oil 19 within the containers.

The optical system, being mounted on the gun, partakes of all movements thereof, but the line of sight is displaced with respect to the gun by the computing mechanism described below. In such mechanisms, the ultimate effect is always to advance the axis of the gun ahead of the line of sight through the predicted angle λ (Fig. 6), which may be resolved into prediction angles in train and in elevation. This advance in angle may be secured by displacing the line of sight through an angle (−λ) with respect to the gun, as is done in the present application, since the gunner, by always keeping the line of sight on the target, will thereby advance the gun through the angle λ.

Two gyroscopes 20 and 21, of the angular rate or two degree of freedom type, are shown, one of which is responsive to tilt of the gun in elevation and the other to turning of the gun about an axis perpendicular to the gun barrel and to axis 5—5. In Fig. 1, the showing of the gyroscopes is simplified, reference being had to Fig. 2 for specific constructional details, especially of the mounting, spring centralizing, damping and temperature maintaining devices for the gyroscopes. As shown in Fig. 1, the gyroscope 20 is mounted with its two degrees of freedom at right angles to the gun trunnions 5, 5, i. e., it is mounted for precession about the trunnion axis 22, 22′, which is parallel to the gun barrel, and with the spin axis 23 of the rotor 24 perpendicular to the gun barrel and axis 5—5. The other gyroscope 21, on the other hand, is shown as having its trunnions 25 parallel to the gun barrel, with the spin axis 26 of the rotor 27 parallel to the trunnion axis 5, 5 of the gun, so that it is responsive to turning of the gun in traverse or, more precisely, in the slant plane containing the axis 5—5 and the axis of the barrel 2. Therefore, angular movements of the gun in elevation will cause precession of the gyro 20 in one direction or the other, through an angle proportional to said rate of movement against resilient centralizing means, hereinafter described, which rocks the arm 28 connected to trunnion 22′, to thereby rock bell-crank lever 29 and thus rock the arm 30 on the trunnion shaft 7 of the mirror 6, to give the same a displacement proportional to the rate of turn of the gun in elevation, which is modified by the time of flight of the shell, as hereinafter described.

Similarly, turning of the gun in azimuth (using this term broadly) will cause movement of the arm 28′ connected to the trunnion 25′, to rock the arm 31 connected to the trunnion 12 of the mirror 10, which has the effect of displacing the line of sight in this plane due to the 45° mounting of the two mirrors 6 and 10.

Preferably, both gyroscopes are spring centralized and pivotally supported by spring suspension means. One trunnion, shown as the rear trunnion 22′ or 25′, of each gyroscope is spring supported and centralized by means of a plurality of tangentially directed leaf springs 32, 32′, 33, 33′, symmetrically arranged around each trunnion and connected thereto by radially extending connecting members 34 and 35 which are shown as in the form of wires passing through a clamp or block 36 secured to the trunnion. At the two outer ends, each wire is clamped in other blocks 37, 37′, 38, 38′, which are also clamped adjacent the free end of respective leaf springs 32, 32′, 33, 33′. In Fig. 3, the bending or leaf springs 32, 33 are shown as anchored to the casing by being clamped in ears 42 extending from the rear end of the casing. It will readily be seen that upon precession of the gyroscope, each trunnion will be turned, thus twisting the wires 34, 35 and pulling their outer ends inwardly against the spring force of the relatively stiff leaf springs. While this resistance to precession is mainly exerted by the bending or leaf springs through the connecting tension wires, there is also a slight force exerted due to the bending of the wires themselves.

The opposite trunnions of the gyroscope, however, are preferably supported and spring centralized by a different type of tension wire which also acts to prevent axial displacement of the trunnions. In other words, this wire also acts to centralize the gyro rotor bearing frame 40 within the gyro housing 41 to which the several springs are anchored at their fixed ends. At its forward end, the casing is shown as provided with a U-shaped bracket 43 (Figs. 2 and 4), and tightly drawn between the open ends of the U is a single wire 44, here shown as being clamped in clamping blocks 45. To the gyro trunnion 25 is shown secured an open framework 46, the legs of which pass around the inner U-arm 45′. Said frame 46 at its outer end is shown as clamped to the middle of the wire 44 by clamp screw 47. This wire therefore acts as a pivotal support for the rotor bearing frame 40 at its forward end. Also, by its resistance to twisting, it acts as a resilient centralizer for the frame to oppose precession, and in the third place, it prevents axial shift of the rotor bearing frame in either direction, thus supplementing the action of the leaf spring and wire members at the other end, which have little axial resistance.

It is also important that the precessional movements be heavily damped. Preferably the damper is of such a form that it also suppresses any bouncing or oscillation of the gyroscope in its spring supports. Such damping means is shown as in the form of circular oil containers **48** placed at each end of the gyro casing **41**, and which are partially filled with heavy oil or gum. A disc-like member **49** secured to the trunnion or rotor frame is placed within each container. Preferably, the members **49** have axially extending or rim portions **50** at their periphery, the housing **48** closely surrounding but not touching the same. These discs therefore interpose a damping resistance to translatory oscillations of the gyro frame in any plane, as well as to rotary movements due to precession. The rims also materially aid in the effective damping of the precessional movements.

It is important that the damping coefficient remain substantially constant in order that the proper "characteristic time" of the gyroscope may be preserved. To this end, we prefer to incorporate in the gyro housing a means for maintaining the temperature of the damping fluid constant, which may be achieved by utilizing electrical heating coils **51**, **52** placed next to the containers **48**, controlled by a thermostatic means (not shown) adjusted to maintain the temperature at a fixed point higher than would be met at any time from natural causes. A temperature well above 100°F. is suggested for the purpose.

In order to introduce the time-of-flight factor, we vary the sensitivity of the gyroscope, preferably by varying the spring force which opposes precession of the gyroscope. While this may be done by varying the tension of the leaf springs of Fig. 3, we prefer to utilize a separate spring system for this purpose. As shown, there is fixed to each trunnion **22'**, **25'** an arm **53** carrying spaced knife edges **54** and **55**, each normally held between a pair of leaf springs **56**, **56'** and **57**, **57'** so that the bending force of the spring system opposes precession of the gyro in each direction. To vary this bending force with the time of flight or range, we have shown each pair of springs as mounted on an adjustable bracket **58**, **58'**, and the two brackets are movable equally and oppositely, as by being provided with oppositely facing rack bars **59**, **59'** meshing with a common pinion **60** on the shaft of a gear **61**.

It will readily be apparent that by rotating said gear, the stiffness of the springs may be readily varied. For this purpose, there is shown a time-of-flight or range dial **62** which is shown as turning the gear **61** through a suitable gear connection **63**. Preferably, a single range setting should be used to shift the spring system equally on both gyroscopes. For this purpose, the gear system **63** is shown as also meshing with a similar gear **61'** on the shaft of a similar pinion **60'** meshing with the rack bars on the spring system on the other gyroscope.

For satisfactory operation of the apparatus described above, certain relationships (within tolerable limits) between the physical constants must be maintained. These relationships are necessary to prevent instability, and also, to minimize the dynamic error under conditions of changing lead angle. These conditions will be best understood from the following mathematical discussion. This analysis may be carried out for one gyro only, since any motion may be resolved into components affecting the two gyros independently.

Let:

I= the moment of inertia of the rotor bearing frame and its rotor about the precession axis **22**, **22'**, or **25**, **25'**.

c=the coefficient of damping for angular displacement about said axis, or

$$c=\frac{\text{damping torque}}{\text{angular velocity of precession}}$$

k=the elastic constant of the springs opposing angular displacement about said axis, or

$$k=\frac{\text{elastic torque (of spring)}}{\text{deflection angle (angle of precession)}}$$

θ=the deflection (precession) angle of the gyro support about the precession axis from its normally central position, due to a precession causing torque

H=the angular momentum of the gyro rotor about its spin axis (moment of inertia of rotor about spin axis x angular velocity of spin)

ωG=the angular velocity of the gun

ω=the angular velocity of the line of sight

λ=lead angle between line of fire and line of sight.

Owing to the fact that the gyro is mounted on the gun, the precessional torque is proportional to the angular velocity of the gun. Expressed symbolically, this torque is $H\omega_G$. But the gunner operates the gun from the line of sight, and it is the line of sight which determines the lead prediction. The angular velocity of the gun is equal to the angular velocity of the line of sight plus the rate of change of the lead angle; that is,

$$\omega G=\omega+\frac{d\lambda}{dt} \qquad (1)$$

The precessional torque is, therefore,

$$H\omega+H\frac{d\lambda}{dt} \qquad (2)$$

The lead should be determined from the motion of the target which appears in the equation as the angular velocity of the line of sight. The quantity

$$H\ \frac{d\lambda}{dt}$$

may therefore be considered as a false-prediction torque. It has a definite value except when the angular velocities of the gun and of the line of sight are equal.

According to the invention, we neutralize the false-prediction torque by introducing a dissipative torque which is proportional to the rate of change of lead angle. For this purpose we preferably apply a torque by viscous damping, which torque is proportional to the rate of precession of the gyro, which in turn is proportional to

$$\frac{d\omega G}{dt}$$

or angular acceleration of the gun.

The analysis may be carried further by equating the torque of Equation 2 to the torques which oppose the precession. These latter torques are

(A) the inertial torque $I\frac{d^2\theta}{dt^2}$

(B) the damping torque $c\frac{d\theta}{dt}$, and

(C) the elastic torque $k\theta$

Then

$$I\frac{d^2\theta}{dt^2}+c\frac{d\theta}{dt}+k\theta=H\omega_G \qquad (3)$$

$$=H\left(\omega+\frac{d\lambda}{dt}\right) \qquad (4)$$

This equation may be expressed throughout in terms of the lead angle λ.

Let S=the sensitivity=

$$\frac{\text{indicated angle of lead}}{\text{angular velocity of gun}}=\frac{\lambda}{\omega_G}=\frac{\lambda}{\theta}\,\frac{\theta}{\omega_G}=\frac{\lambda}{\theta}\,\frac{H}{k}$$

the last transformation being obtained from (3) by considering the condition of constant deflection angle.

Then

$$\theta=\frac{H}{kS}\lambda$$

and (4) becomes:

$$\frac{HI}{kS}\frac{d^2\lambda}{dt^2}+\frac{cH}{kS}\frac{d\lambda}{dt}+\frac{H}{S}\lambda=H\omega+H\frac{d\lambda}{dt} \qquad (5)$$

The false-prediction torque

$$H\,\frac{d\lambda}{dt}$$

can be entirely removed by making the dissipative or damping torque

$$\frac{cH}{kS}\frac{d\lambda}{dt}$$

exactly equal thereto. Actually, for reasons of stability, as will be presently explained, it is desirable to introduce slightly more damping than is necessary to wipe out the false-prediction torque. For convenience, let

$$\frac{c^{-1}}{kS}=\sigma$$

It is important to note that the damping coefficient c is maintained constant, and that the sensitivity S is always inversely proportional to the elastic constant k, wherefore σ is a design constant of the equipment.

Then (5) reduces to the second order equation:

$$I\frac{d^2\lambda}{dt^2}+kS\sigma\frac{d\lambda}{dt}+k\lambda=kS\omega \qquad (6)$$

For constant angular velocity (and therefore constant lead angle), the solution is simply

$\lambda=S\omega$ and since λ should also be equal to $T\omega$

this means that S is made, by calibration, equal to the time of flight (T) and the shell will meet the target at the point predicted by the instrument.

In general, however, the angular velocity is not constant. A more complete solution can be obtained by standard methods if ω is known as a function of time, and if k is assumed constant, as it will be for any time-of-flight setting. For purposes of explanation, it will be sufficient to assume that the inertial torque is negligible, so that (6) reduces to a first order linear equation:

$$\sigma S\frac{d\lambda}{dt}+\lambda=S\omega \qquad (7)$$

Without going through the steps of integration, it may be shown that the solution of (7) involves

(a) a transient term of the form

$$C\epsilon-\frac{t}{\sigma S}$$

where the constant C is determined from the "initial conditions," and

(b) an error term, which may be called the "forced dynamic error," due to acceleration effects, that is to say, departure of ω from a constant value.

Both the transient and forced dynamic error are zero if $\sigma=0$. It should be noted, however, that if σ is even slightly negative, the transient will be one which grows indefinitely with increasing time; in other words, the system is unstable and satisfactory operation would be impossible. The condition of negative σ means that the false-prediction torque has not been completely wiped out by the dissipative torque.

Complete neutralization ($\sigma=0$) would leave the instrument on the verge of instability, with the possibility of unstable operation in the event of a slight change in any of the physical constants. Accordingly we made σ slightly greater than zero, that is, we not only neutralize the false-prediction torque but apply enough excess damping to insure stability under all conditions. When the constant σ has been once adjusted, it is constant for all time-of-flight settings; a change in sensitivity S does not affect stability.

The forced dynamic error is proportional to σ S. The constant σ should therefore be made small. It has been found that the preferred value is in the neighborhood of 0.2, but values in the range from 0.05 to 0.50 have been found satisfactory in practice.

It is not necessary to assume that the inertial torque is negligible. A solution of (6) gives the same criterion of stability. Usually, however, the moment of inertia about the precession axis is small enough so that the first order equation correctly expresses the dynamic response of the system.

Tracking errors necessarily appear in any fire control system, but theory and practice both indicate that in our invention, if the coefficients are properly fixed as described above, tracking errors are not of primary importance, and it is here that our invention has an important advantage over the director type of fire control.

By tracking errors are meant those errors due to inability of the operator to mechanically position a device. It can be stated as a general rule that in any fire control device whatever, in which conditions of stability are satisfied, tracking errors of the gun are always greater than tracking errors of the sighting element. The gun of the present invention can be operated as accurately as the sight of the director system, but in the latter, the errors are magnified at the gun.

In the present case, any tracking errors introduced in the operation of the gun appear as reduced fluctuations in the line of sight. The smaller the value of σ, the more will the fluctuations of the line of sight be reduced. Elimination of such fluctuations would not be desirable, because of the loss of sensitivity, but it has been found that if σ lies in the preferred range between 0.05 and 0.50, the line of sight has the desired characteristics of smooth operation and sensitive response to the motion of the gun.

In actual operation, the time of flight is varied by adjusting the spring constant, preferably as shown in Figs. 7 and 8. In any case, the damping coefficient when once adjusted is kept unchanged. As brought out in the foregoing mathematical theory, so long as the damping coefficient is unchanged and variations are made only in the spring constant, the necessary conditions of stability are always maintained.

The setting of the damping coefficient is best accomplished in a test set-up. A simple test is to impart to the entire gyro mechanism (not necessarily mounted on a gun) a sudden angular movement from a position of rest. If the smoothing factor σ is negative, the line of sight will first jump in the direction opposite to the movement of the device. If σ is positive but too large, the line of sight will start to move immediately in the proper direction, but will not quickly assume a constant angular displacement. But if the factor has a correct value slightly greater than zero, the sighting element will hesitate for an instant, and then will follow the angular motion at a constant angular displacement.

Another method of test is to move the mechanism at a constant angular velocity, stop the movement suddenly when the sight reaches a fixed target, and then move the mechanism back while maintaining the sight on the target. If σ has a negative value, it will be found practically impossible to hold the sight on the target, and if it is positive but too large, the action will be sluggish and an unduly long time will be required to move the mechanism back to the target. But if σ is positive and within the proper range, this test operation can be easily and quickly carried out.

Either or both of these test methods may be used. They conform to the natural reactions of the gunner, and they correspond to conditions actually met in the field. If unstable conditions are indicated in the test, they may be corrected by adjusting the damping coefficient, preferably by adjusting the controlled temperature of the damping medium. This is a "factory adjustment" which is thereafter permanently maintained, with assurance of stable operation under all conditions.

The invention also contemplates the addition of certain "biasing" torque about the precession axis. In fire control these torques act to apply automatic corrections for super-elevation, cross-wind and the like. The effect of such a torque is to shift the neutral or zero position of the reticle.

An approximate formula for the superelevation necessary to correct for the effect of gravity on the shell is superelevation $\equiv$ a constant $\times S \times \cos E$ where E is the angular elevation of the gun above the horizon.

Since S is taken care of by the adjustment of the springs **56** and **57**, or in other words, since the formula used in this sight for angular prediction is based on the presumption that the gyro sensitivity is proportional to time of flight, any additional torque applied to the gyro gimbal frame produces an angular deflection of the line of sight that is also proportional to time of flight.

For the superelevation correction, we obtain the factor cos E in an extremely simple and effective manner. We fix to the gyro trunnion **22** of the elevation gyro **20** a laterally extending arm **64** on which is placed a weight **65** which may be adjusted for the ballistics of the particular gun and left in place, regardless of the range. This weight, it will be seen, will, when the gun barrel is horizontal, i. e., when $E=0$, exert its full torque on the gyroscope, the cosine of zero being 1. As the gun barrel is elevated, however, the torque exerted by the weight will decrease in accordance with the cosine function of E and therefore the weight will exert the correct torque for introducing the proper superelevation correction for all elevations of the gun as long as the gyro trunnions **5**, **5** remain horizontal.

In case, however, the gyro trunnions become inclined due to roll or pitch of the ship, a study of the problem will show that only a component part of the correction will be generated by the mass **65** on the gyro **20**. However, the other component may be introduced by placing a similar arm **64'** and mass **65'** on the other gyroscope **21**, but extending the arm in this case perpendicularly instead of laterally. When the gun trunnions are horizontal, therefore, the mass **65'** has no effect on the gyro **21**, regardless of the elevation of the gun barrel. In case, however, the trunnions **5**, **5** become inclined, the gyro, being constrained to follow the gun, will also become tilted and tilt with it the arm **64'**, which will therefore exert a torque on the gyro proportional to the sine of the inclination of the trunnions **5**, **5**. Therefore these two components, entering together into the optical system, will give the proper superelevation angle.

A method of taking care of the effect of cross-wind is to employ variable tension springs to exert a torque on the gyroscope, adjustable with cross-wind velocity, as illustrated in Fig. 7. In this figure, the U-shaped bracket **43'** between the arms of which the centralizing wire **44'** is stretched, is shown as adjustable about the wire as a center. For this purpose, the arm is shown as provided with segmental worm teeth **80** with which a worm **81** on shaft **82** meshes. By turning the knob **83** on said shaft to position a pointer **84** with respect to arbitrary wind velocity markings **85**, a wind correction may be introduced.

Another method of introducing such correction is represented diagrammatically in Fig. 8. In this figure, the trunnion **25'** of the gyroscope is provided with radial arms **86** carrying arc-shaped cores **87** adapted to enter solenoids **88**. By variably exciting the solenoids, as by means of a rheostat **89** having suitable graduations **90**, the proper torque may be applied for wind or other corrections.

While the corrective torque described in connection with either Fig. 7 or 8 may also be applied to the elevation gyroscope **20**, being made proportional to the head wind, i. e., the wind velocity along the line of fire (which has the effect of retarding or lessening the retardation of the shell), it is preferred to introduce the correction for head wind by introducing a correction for the same into the time of flight setting through knob **62**.

Spotting corrections are preferably introduced by adjustment of the reticle with respect to the optical system with the gyroscopes in their centralized position, as shown in Fig. 1. The reticle is adjusted in elevation by a set screw **66** and in azimuth by a set screw **67**, by which corrections for wind or spotting corrections may be easily introduced by adjusting graduated knobs **66'** and **67'**, respectively.

The bias torques introduced as above described do not alter the dynamic characteristics of the system. This can be seen from Equation 4. If a constant torque is added to the precession torque on the right-hand side of the equation, the criteria of stability are in no way affected.

The gyros are shown as air spun by means of air nozzles **68** and **69**, and the speed of each may be carefully adjusted by the valves **70**. Preferably, also, a thermostatically controlled air heater **71** is placed in the air supply so that great fluctuations will not occur in the temperature of the air supplied within the casing. A common pressure regulating valve is shown at **91**.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

An example of one such modification is illustrated in Fig. 9, showing an alternative form of tension wire support and centralizing means for the gyroscope. As suggested in this figure, axially extending wires similar to wire **44** of Fig. 1 may be used at each trunnion of the gyroscope, as shown at **44** and **92**, and the radially extending wires **34**, **35** omitted. Thus tension wire **92** is connected at its middle to a cross bar **53′** connected through the knife edge pins **54′**, **55′** to the arm **53** connected to the forward trunnion, the wire **92** being, as before, tightly held between supports **95** and **96**. Leaf springs **56** and **57** are omitted in Fig. 9 for the sake of clearness. At the rear, the wire **44** may be supported in brackets **45′**, as in Fig. 1, the trunnion being secured to the middle portion of the wire through the open frame **46′**. It will, of course, be understood that the damping discs and housings **48** are retained in all forms so as to damp the precession of the gyroscope and suppress vibration and oscillation.

The feature of applying a bias torque for purposes of correction is not limited to the apparatus in which the gyro is mounted on the gun but may be applied to any type of lead computing or rate measuring gyroscope.

Although the invention has been specifically described as embodied in a sighting device for guns, it will be understood that the invention is not limited to such embodiment but is applicable to other systems for measurement or indicating of rates of angular movement.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a predicting device for fire control, the combination of a gun element and the sighting element therefor, a rate gyroscope mounted on the gun element for precession through an angle proportional to the rate of turn thereof, resilient means having an elastic constant (k) acting about the precession axis of said gyroscope for centralizing said gyroscope, damping means also acting about the precession axis having a damping constant (c) opposing motion about the axis of precession substantially in proportion to the velocity of the motion, said elastic and damping constants having values such that

$$\frac{c}{kS}>1$$

where S is the sensitivity of the device, and means actuated by the precessional movements of the gyro for introducing a prediction or lead angle between the gun and sighting elements proportional to said angle of precession.

2. In a predicting device for fire control, the combination of a gun element and the sighting element therefor, a rate gyroscope mounted on the gun element for precession through an angle proportional to the rate of turn thereof, resilient means having an elastic constant (k) for centralizing said gyroscope, damping means having a damping constant (c) opposing motion about the axis of precession substantially in proportion to the velocity of the motion, said elastic and damping constants having values such that

$$\frac{c}{kS}$$

is between 1.05 and 1.50, where S is the sensitivity of the device, and means actuated by the precessional movements of the gyro for introducing a prediction or lead angle between the gun and sighting elements proportional to said angle of precession.

3. In a predicting device for fire control, the combination of a gun element and the sighting element therefor, a rate gyroscope mounted on the gun element for precession through an angle proportional to the rate of turn thereof, means responsive to said precession for introducing a prediction or lead angle between the gun and sighting elements proportional to said angle of precession, resilient means having an elastic constant (k) for centralizing said gyroscope, and damping means having a damping constant (c) opposing motion about the axis of precession substantially in proportion to the velocity of the motion, said elastic and damping constants having values such that

$$\frac{c}{kS}$$

is between 1.05 and 1.50, where S is the sensitivity of the device, said value of

$$\frac{c}{kS}$$

being maintained substantially constant for all sensitivity settings by adjusting S substantially in inverse proportion to k.

4. In a gyro sight, a target following device including gun and sight elements, a spring-centralized rate gyroscope adapted to be mounted on said device mounted for turning in azimuth and for turning in elevation about a normally horizontal trunnion axis, said gyroscope being mounted for precession about an axis perpendicular to said trunnion axis by reason of and upon angular movements of said device in elevation, means actuated from said gyroscope for introducing a predicted correction in elevation between the sight and gun variable with angular velocity of said device, and a mass eccentrically secured to said gyroscope with respect to said precession axis and adapted to exert a torque on the gyroscope about said axis proportional to the cosine of the angle of elevation of said device about its trunnion axis.

5. A gyro sight as claimed in claim 4, having a second gyroscope mounted for precession about an axis parallel to the precession axis of the first gyroscope upon turning of the device in azimuth, an eccentric mass secured to the trunnion axis of said second gyroscope which exerts a torque thereon only when the trunnion axis of said device is inclined to the horizontal, a means connecting both gyroscopes to the sight element to give the same a lead angle in both train and elevation.

6. In a prediction or lead computer of the angular rate type for guns, a lead angle indicating device, a pair of gyroscopes adapted to be mounted on the gun, one mounted for precession upon turning of the gun in elevation and the other mounted for precession upon turning of the gun in the slant plane determined by its trunnion and bore axes, means connecting both gyroscopes to the indicating device to cause movement thereof proportional to the precessional movements of

the gyroscopes, a superelevation weight secured to the first named gyroscope and adapted to exert thereon a torque proportional to the cosine of the angle of elevation, and a superelevation weight secured to the other gyroscope adapted to exert thereon a torque proportional to the sine of the inclination angle of said trunnion axis.

7. In a prediction mechanism for guns, a pair of gyroscopes mounted on a target following device, said device including a lead angle indicating mechanism, one gyroscope being mounted for precession upon turning of the gun in elevation and the other mounted for precession upon turning of the gun in the slant plane determined by its trunnion and bore axes, means connecting the gyroscopes to the indicating mechanism to cause movement thereof proportional to the precessional movements of the gyroscopes, and means for applying a biasing torque about the precession axis of the latter gyroscope proportional to the component wind velocity across the line of fire.

8. Prediction mechanism for guns as claimed in claim 7, wherein said biasing torque means includes an electromagnetic torque and means for varying the energization thereof proportionally to the component of wind velocity across the line of sight.

9. In a prediction or lead computer of the angular rate type for guns, a gyroscope adapted to be mounted on a target following device for precession about an axis due to and upon movement of the device in elevation, a sight operated in accordance with the precession, resilient centralizing means for opposing precession in either direction, means for adjusting the precessional sensitivity of the gyroscope for varying ranges, means for altering the normal centralized position of the gyroscope for applying wind corrections, and means for giving the sight a lead angle relative to the gun from the precession of said gyroscope while said device is following a target.

10. In a prediction or lead computer of the angular rate type for guns, a gyroscope adapted to be mounted on a target following device for precession about an axis due to and upon movement of the device in elevation, resilient centralizing means for opposing precession in either direction, and means for introducing a superelevation correction comprising a mass eccentrically secured to said gyroscope with respect to the precession axis and adapted to exert a torque thereon varying with a function of the angle of elevation of the device.

11. in a prediction or lead computer of the angular rate type for guns, a gyroscope adapted to be mounted on a target following device for precession about an axis due to and upon movement of the device in the slant plane determined by its barrel and trunnions, resilient centralizing means for opposing precession in either direction, means for adjusting the precessional sensitivity of the gyroscope for varying ranges, and an eccentric mass secured to said gyroscope above its precession axis and adapted to exert a torque thereon when said trunnion axis is inclined to the horizontal proportional to the sine of the angle of inclination.

12. In a gyroscopic lead computer for gun sights, a spring-centralized gyro movable with said sight and having an axis of rotation perpendicular to said axis of movement, an indicating device operated by precession of the gyro, a spring centralizer for the gyro, torsion means for the spring centralizer to apply a bias torque to the gyro about the axis of precession thereof, and means for adjusting said means to correct for cross wind.

13. In a gyroscopic lead computer for gun sights, a spring-centralized gyro movable with said sight and having an axis of rotation perpendicular to said axis of movement, an indicating device operated by precession of the gyro, a spring centralizer for the gyro, and torsion means for the spring centralizer to apply a bias torque to the gyro about the axis of precession thereof, said torsion means including a solenoid and a core attracted thereby and connected with said centralizer.

14. In a gyroscopic lead computer for gun sights, an angular rate gyroscope including a resilient restraint opposing precession thereof, said gyroscope being adapted to be mounted on a gun for precession against the opposition of said restraint through an angle proportional to the rate of turn of the gun, means operated from said gyroscope in accordance with such precession for imparting a proportional negative lead angle to the sight, and damping means for retarding change of said lead angle during acceleration of the gun, said damping means comprising a viscous drag device acting about the precession axis of the gyroscope and having thermostatically controlled means for maintaining the temperature and thereby the viscosity thereof.

15. In a predicting device for fire control, a sight comprising adjustable means defining a line of sight, a rotatable support, means for mounting said sight for displacement relative to the support, a rate gyroscope mounted on said support for precession in proportion to the rate of rotation of the support, a resilient restraint opposing precession of said gyroscope and having an elastic coefficient K, means damping precession of said gyroscope, and means for adjusting said resilient restraint, to alter the amount of displacement of the line of sight relative to the support upon precession of said gyroscope, said adjustment having a sensitivity constant S with respect to the rate of rotation of said support, said damping means having a damping constant c, and said constants having the relationship

$$\frac{c}{kS}>1$$

16. A lead computing device to compute an angular lead between a primary driven element and a line of sight element comprising an angular rate gyro to be bodily turned with the driven element and capable of precession through an angle substantially proportional to the rate of turn thereof and having a sensitivity S, connections for operating the line of sight element in accordance with the precession to introduce an angle λ between the driven element and the line of sight element, whereby the device is subject to an instability-producing torque which is a function of

$$\frac{d\lambda}{dt}$$

resilient centralizing means having an elastic coefficient K opposing the precessional torque of the gyro, and means for applying about the axis of precession a dissipative torque of coefficient c proportional to

$$\frac{d\lambda}{dt}$$

and to KS to neutralize the instability-producing torque.

17. A lead computing device to compute an angular lead between a primary driven element and an indicating element comprising an angular rate gyro to be bodily turned with the driven element and capable of precession through an angle substantially proportional to the rate of turn thereof, connections for operating the indicating element from and in accordance with the precession to introduce an angle λ between the driven element and the indicating element whereby the device is subject to an instability-producing torque which is a function of

$$\frac{d\lambda}{dt}$$

resilient centralizing means having an elastic constant k to oppose the precessional torque, and means for applying about said axis a damping torque proportional to

$$\frac{d\lambda}{dt}$$

the damping means having a damping coefficient c, the relation of the constants being such that

$$\frac{c}{kS}$$

is a constant greater than unity, where S is the sensitivity of the device.

18. A lead computing device to compute an angular lead between a primary driven element and a line of sight element comprising an angular rate gyro to be bodily turned with the driven element and capable of precession through an angle substantially proportional to the rate of turn thereof, connections for operating the line of sight element in accordance with the precession to introduce an angle λ between the driven element and the line of sight element, whereby the device is subject to an instability-producing torque which is a function of

$$\frac{d\lambda}{dt}$$

resilient centralizing means opposing the precessional torque of the gyro, means for applying about the axis of precession a dissipative torque proportional to

$$\frac{d\lambda}{dt}$$

to neutralize the instability-producing torque, and means for adjusting the sensitivity S in inverse proportion to the elastic coefficient k, whereby stability is uniformly maintained without variation of the damping coefficient.

19. A lead computing device to compute an angular lead between a primary driven element and an indicating element comprising an angular rate gyro to be bodily turned with the driven element and capable of precession through an angle substantially proportional to the rate of turn thereof, connections for operating the indicating element in accordance with the precession to introduce an angle λ between the driven element and the indicating element, whereby the device is subject to an instability-producing torque which is a function of

$$\frac{d\lambda}{dt}$$

resilient centralizing means having an elastic constant k to oppose the precessional torque, and means for applying about said axis a damping torque proportional to

$$\frac{d\lambda}{dt}$$

the damping means having a damping coefficient c, the relation of the constants being such that

$$\frac{c}{kS}$$

is a constant between 1.05 and 1.50, where S is the sensitivity of the device.

20. A lead computing device to compute an angular lead between a primary driven element and a line of sight element comprising an angular rate gyro to be bodily turned with the driven element and capable of precession through an angle substantially proportional to the rate of turn thereof, connections for operating the line of sight element in accordance with the precession to introduce an angle λ between the driven element and the line of sight element, whereby the device is subject to an instability-producing torque which is a function of

$$\frac{d\lambda}{dt}$$

resilient centralizing means having an elastic constant k to oppose the precessional torque, and means for applying about said axis a damping torque proportional to

$$\frac{d\lambda}{dt}$$

the damping means having a damping coefficient c, the relation of the constants being such that

$$\frac{c}{kS}$$

is a constant between 1.05 and 1.50, where S is the sensitivity of the device, and means for adjusting the sensitivity S in inverse proportion to the elastic coefficient k, whereby stability is uniformly maintained without variation of the damping coefficient.

21. A predicting device for laying a gun in elevation from a line of sight comprising a rate gyro mounted to be bodily turned in elevation with a gun and capable of precession through an angle substantially proportional to the rate of turn thereof, means for applying to the gyroscope about the axis of precession a stiffness or centralizing torque and a dissipative torque, means for computing a lead angle in elevation therefrom including connections for causing the line of sight to lag behind the turning of the gun from the gyro precession in accordance with the amount of precession, and means for applying about the axis of precession of said gyro a superelevational biasing torque to the gyro proportional to gravitational force and to the cosine of the angle of elevation.

22. A predicting device for fire control comprising a rate gyro mounted to be bodily turned in elevation with a gun and capable of precession through an angle substantially proportional to the rate of turn thereof, means for applying about the axis of precession a stiffness torque and a dissipative torque, lead angle indicating means, connections for operating the indicating means from the gyro in accordance with the precession, and a mass mounted on said gyro eccentrically with respect to said axis to introduce a superelevational correction to the gyro proportional to the cosine of the angle of elevation.

23. A predicting device for fire control as claimed in claim 21, having a second gyro having its spin axis normal to the spin axis of the first gyro and adapted to be turned in azimuth with the gun and capable of precession upon such turning movements, means for computing a lead train angle therefrom including connections for

causing the line of sight to lag behind the turning of the gun in accordance with the precession of said second gyro, and means for applying about the precession axis of said second gyro a biasing torque due to gravity only when the spin axis of said second gyro is inclined from horizontal.

24. A predicting device for fire control as claimed in claim 22, having a second gyro having its spin axis normal to the spin axis of the first gyro and adapted to be turned in azimuth with the gun and capable of precession upon such turning movements, connections for operating the indicating means from said second gyro in accordance with the precession of said second gyro, and means for applying about the precession axis of said second gyro a biasing torque due to gravity and proportional to the sine of the angle of inclination of the spin axis of said second gyro from horizontal.

25. In a lead computer of the angular rate type, a rate of turn gyroscope, means for resiliently centralizing the same, lead indicating means actuated by precession of said gyroscope, means for introducing a cross wind correction into said computer, said means including means for shifting the null position of the centralizing means for altering the normally centralized position of the gyroscope and a scale representing cross wind velocity by which the centralized position of gyroscope may be altered for different wind velocities.

26. In a gyroscopic lead computer for gun sights, an angular rate gyroscope including a resilient restraint opposing precession thereof, said gyroscope being adapted to be mounted on a gun for precession against the opposition of said restraint through an angle proportional to the rate of turn of the gun, means operated from said gyroscope in accordance with such precession for imparting a proportional negative lead angle to the sight, and damping means modifying the response of the gyroscopic precession to change of velocity of the gun so constructed and arranged with respect to the resilient restraint as to prevent said lead angle from changing at a rate greater than the angular velocity of the gun, said damping means including a viscous drag device acting about the precession axis of the gyroscope and having thermostatically controlled means for maintaining the temperature and viscosity thereof constant.

27. An angular rate gyroscope comprising a gyroscopic rotor and rotor bearing frame, a pivotal support mounting said frame for precession including a trunnion and a plurality of springs arranged around said trunnion and connected thereto at spaced points so as to pivotally support and yieldingly centralize said frame, and a two-part liquid damper for said gyroscope, one part of which is rotatable with said gyroscope and comprises a disc having an axially extending flange, the other part comprising a closely fitting housing for said disc and flange, whereby translatory vibration of the gyroscope in all directions is damped by said damper as well as the precession thereof.

28. In an angular rate gyroscope, a rotor, a bearing frame within which said rotor is mounted for spinning about an axis, an outer casing, means for pivotally mounting said frame in said casing for precession about a second axis without a bearing, comprising only spring means extending between said frame and said casing for both pivotally supporting and guiding the frame and yieldingly opposing the precession of the gyroscope in either direction from its normal position, a disc on said frame for turning therewith having an axially extending flange, and a closely fitting liquid container surrounding said disc and flange and secured to said casing, whereby transitory vibration of the gyroscope in all directions as well as gyro precession is damped through the action of said liquid filled container on said disc and flange.

29. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, means furnishing a trunnion axis therefor including a plurality of springs for pivotally supporting and resiliently centralizing the same, damping means both for strongly damping precessional movements of said frame about said axis and for suppressing vibrating motion of said frame, and means for adjusting the bending stiffness of at least one of said springs in accordance with the range.

30. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, a trunnion axis therefor including a plurality of springs for pivotally supporting and yieldingly centralizing the same, an additional straight leaf spring for additionally centralizing the gyroscope, and means for varying the effective length of said straight spring for adjusting the bending stiffness thereof in accordance with the range.

31. In a predicting mechanism for a disturbed sight, the combination with a sight adapted to be mounted on a gun, means for causing said sight to lag behind the gun at an angle equal to the predicted lead angle, including a rate of turn gyroscope adapted to be mounted on the gun, resilient means for strongly centralizing the same about its precession axis, viscous means for heavily damping the same about said axis, the damping coefficient having a critical relationship to the other constants of the gyroscope, and means for accurately adjusting the damping coefficient for establishing and maintaining such relationship, comprising an electrical heater for the viscous damper, designed to maintain a temperature above the ambient temperature, and thermostatic means controlling said heater for maintaining such damper at the correct damping coefficient when operating.

32. In a prediction or lead computer of the angular rate type for guns, a gyroscope adapted to be mounted on a target following device for precession about an axis due to and upon movement of the device in elevation, resilient centralizing means for opposing precession in either direction, means for varying the stiffness of said resilient means with range, and means for introducing a superelevation correction, which is correct without adjustment for all normal ranges, comprising a mass eccentrically secured to said gyroscope with respect to the precession axis and adapted to exert a torque thereon varying with a function of the angle of elevation of the device.

33. In a gyro sight, a target following device including gun and sight elements, a spring-centralized rate gyroscope adapted to be mounted on said device mounted for turning in azimuth and for turning in elevation about a normally horizontal trunnion axis, said gyroscope being mounted for precession about an axis perpendicular to said trunnion axis by reason of and upon angular movements of said device in elevation, resilient means for opposing such precession,

means for varying the stiffness of said resilient means in accordance with range, means actuated from said gyroscope for introducing a predicted correction in elevation between the sight and gun variable with angular velocity of said device, and a mass eccentrically secured to said gyroscope with respect to said precession axis and adapted to exert a torque on the gyroscope about said axis proportional to the cosine of the angle of elevation of said device about its trunnion axis, whereby said mass exerts correct superelevation erection regardless of range.

34. In a prediction or lead computer of the angular rate type for guns, a gyroscope adapted to be mounted on a target following device for precession about an axis due to and upon movement of the device in elevation, resilient centralizing means for opposing precession in either direction, damping means for imposing a fixed drag upon such precession, means for introducing a superelevation correction comprising a mass eccentrically secured to said gyroscope with respect to the precession axis and adapted to exert a torque thereon varying with a function of the angle of elevation of the device, and means for varying the stiffness of said centralizing means with range, whereby the correction introduced by said mass remains correct for all ranges.

35. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, a trunnion axis therefor including a plurality of leaf springs for pivotally supporting and yieldingly centralizing the same, and means for adjusting the bending stiffness of at least one of said springs in accordance with the range.

36. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, a trunnion axis for said frame including a plurality of springs including a leaf spring for pivotally supporting and yieldingly centralizing said frame, a damping means for damping precessional movements of said frame about said axis, means for adjusting the stiffness of at least one of said leaf spring in accordance with range, and means for maintaining the strength of the damping means substantially constant.

37. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, means furnishing a trunnion axis therefor including a plurality of springs for pivotally supporting and resiliently centralizing the same, another leaf spring also for resiliently centralizing the same, and means for adjusting the stiffness of said last mentioned leaf spring whereby the characteristic time of the gyroscope may be made substantially equal to the time of flight of the shell.

38. An angular rate gyroscope comprising a gyroscope and rotor bearing frame, a pivotal support mounting said frame for precession including a trunnion, a plurality of springs at said trunnion and connected thereto so as to pivotally support and resiliently centralize said frame, and means for adjusting the stiffness of at least one of said springs for changes in the time of flight of the shell, and a two part liquid damper for said gyroscope, one part of which is rotatable with said gyroscope and comprises a disc having an axially extending flange, the other part comprising a closely fitting housing for said disc and flange, whereby translatory vibration of the gyroscope in all directions is damped by said damper as well as the precession thereof.

39. In a means for laying guns with reference to relatively rapidly moving targets, a sight including a pair of rate of turn type gyroscopes mounted on a gun so as to be turned as the target is followed, pivotal supports for each gyroscope permitting precession about axes at right angles to the axes of turn of the gun, one being responsive to turning of the gun and sight in azimuth and the other to tilting in elevation, centralizing means and damping means acting about the precession axis of both gyroscopes, means for varying the former with the time of flight of the shell, means for maintaining the latter fixed regardless of ambient temperature changes, and means directly actuated by the precessional movements of each of said gyroscopes for relatively displacing the line of sight and gun in train and elevation, said centralizing and damping means being so related that the characteristic time of the gyroscope remains substantially equal to or slightly greater than, the time of flight of the shell.

40. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame, a trunnion axis for said frame adapted to mount the same for precession on a target following device and including a plurality of leaf springs for pivotally supporting and yieldingly centralizing said frame, a damping means for damping precessional movements of said frame about said axis, and means for adjusting the stiffness of at least a portion of said springs, said springs and damping means being so constructed and arranged that the characteristic time of the gyroscope remains substantially equal to the time of flight of the shell.

41. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame mounted for precession about an axis, spring means yieldably centralizing said gyroscope about said axis, a damping means for damping precessional movements of said frame about said axis, means for keeping the damping coefficient of said damping means constant during temperature fluctuations, and means for adjusting the stiffness of said springs with changes in the time of flight of the shell.

42. An angular rate generating device for fire control, comprising a gyroscopic rotor and rotor bearing frame mounted for precession upon angular movement of the line of sight about an axis, means for resiliently centralizing the position of said gyroscope about its precession axis, viscous damping means for damping the precession movements about said axis, thermostatic means for keeping the damping coefficient of said damping means constant during temperature fluctuations, and means for adjusting the elastic characteristics of said resilient centralizing means with the time of flight of the shell.

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